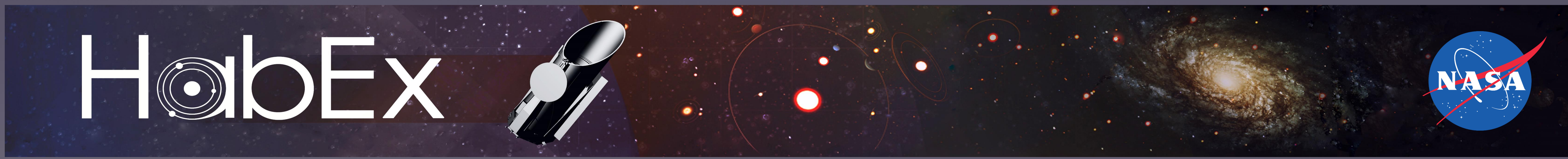

Baseline Telescope: Design & Predicted Performance

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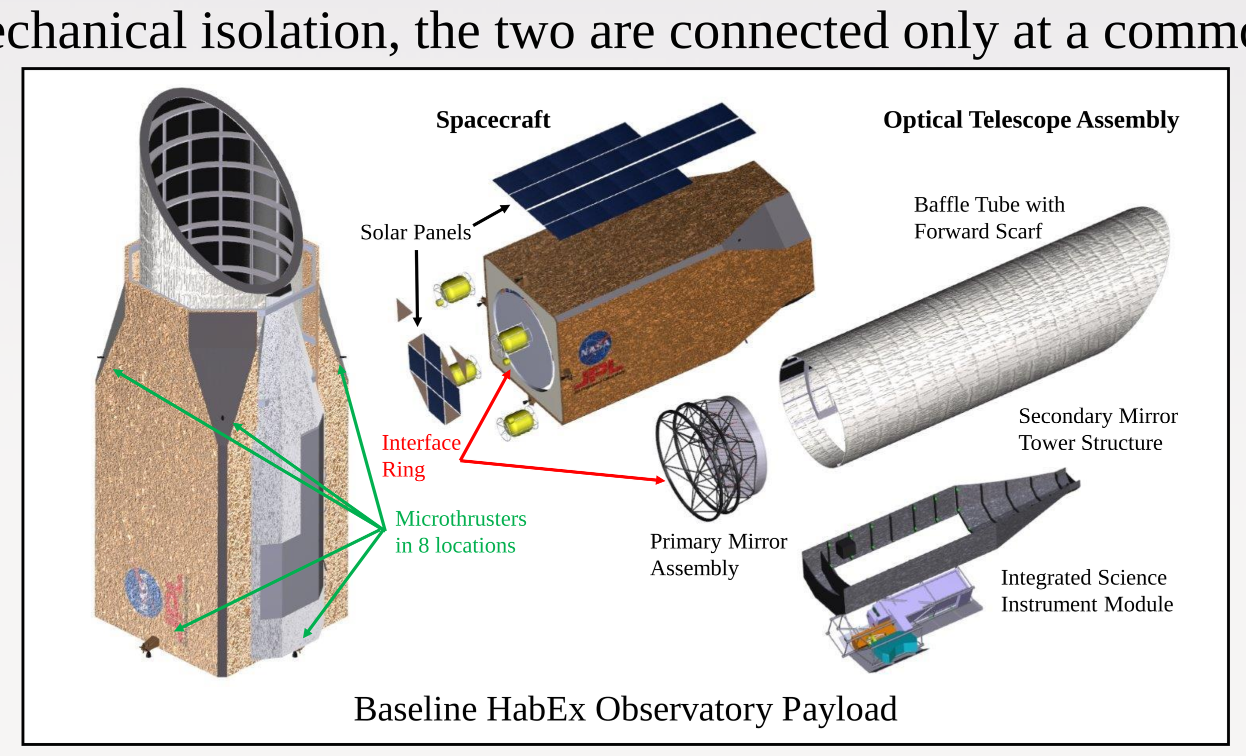
STOP Modeling indicates Baseline Telescope has ultra-stable wavefront for coronagraphy

INTRODUCTION

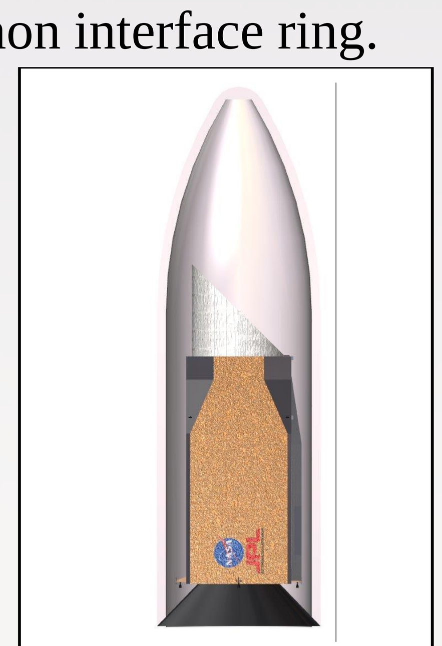
Habitable Exoplanet Observatory Mission (HabEx) will image & spectroscopically characterize planetary systems in the habitable zone around nearby sun-like stars. Additionally, HabEx will perform a broad range of general astrophysics science enabled by a 150 to 1700 nm spectral range and 3 x 3 arc-minute FOV. Critical to achieving the HabEx science goals is a large, ultra-stable telescope. The baseline HabEx telescope is a 4-m off-axis unobscured three-mirror-anastigmatic design with diffraction limited performance at 400 nm and wavefront stability of picometers per mK. These specifications are driven by science requirements. STOP (structural thermal optical performance) analysis predicts that the baseline telescope's opto-mechanical design meets its specified performance tolerances.

BASELINE TELESCOPE

Baseline telescope is a 4-meter off-axis unobscured TMA with a scarfed straylight baffle tube. Spacecraft surrounds telescope providing thermal isolation. For mechanical isolation, the two are connected only at a common interface ring.



Baseline HabEx Observatory Payload



Payload fits in SLS 8.4m fairing.

Baseline telescope achieves its required ultra-stable performance because of the planned Space Launch System (SLS). SLS mass capacity enables an architecture with sufficient mass to design an extremely stiff opto-mechanical structure that can align the primary, secondary and tertiary mirrors to each other and maintain that alignment. Mass also enables thermal stability. STOP analysis predicts that the observatory will have a 20 hour thermal time constant. Additionally, SLS volume enables a monolithic aperture off-axis primary mirror with no deployments.

Design elements critical to achieving ultra-stable performance are stable structure and low disturbance noise. The secondary mirror structure is designed with modes from 11 to 30 Hz and the primary mirror structure is above 40 Hz. To minimize noise, the spacecraft does not use reaction wheels. Instead thrusters are used to slew and point the telescope. After only a 5-minute ring-down period, the WFE is sufficiently stable for coronagraphy. Micro-thrusters are used to maintain pointing during the science exposure. Because the micro-thruster noise spectrum is less than 0.1 micro-Newton and the telescope structure is very stiff, any WFE excited is smaller than the required performance specification.

Thermal stability is enabled via the combination of large thermal mass and TRL-9 active thermal control technology.

WAVEFRONT (WFE) STABILITY

WFE stability is critical for imaging exoplanets with a coronagraph. Instability can result in dark-hole speckles that produce a false exoplanet measurement or mask a true signal. Instability comes from mechanical and thermal sources. Line of sight (LOS) WFE occurs when drift or jitter moves the wavefront laterally on the secondary or tertiary mirror. Inertial WFE occurs when the primary mirror is accelerated by mechanical disturbances causing it to bend against its mounts. Thermal WFE occurs when the temperature of the structure or mirrors changes, causing the mirrors to physically move or change shape due to CTE homogeneity.

WFE STABILITY ERROR BUDGET

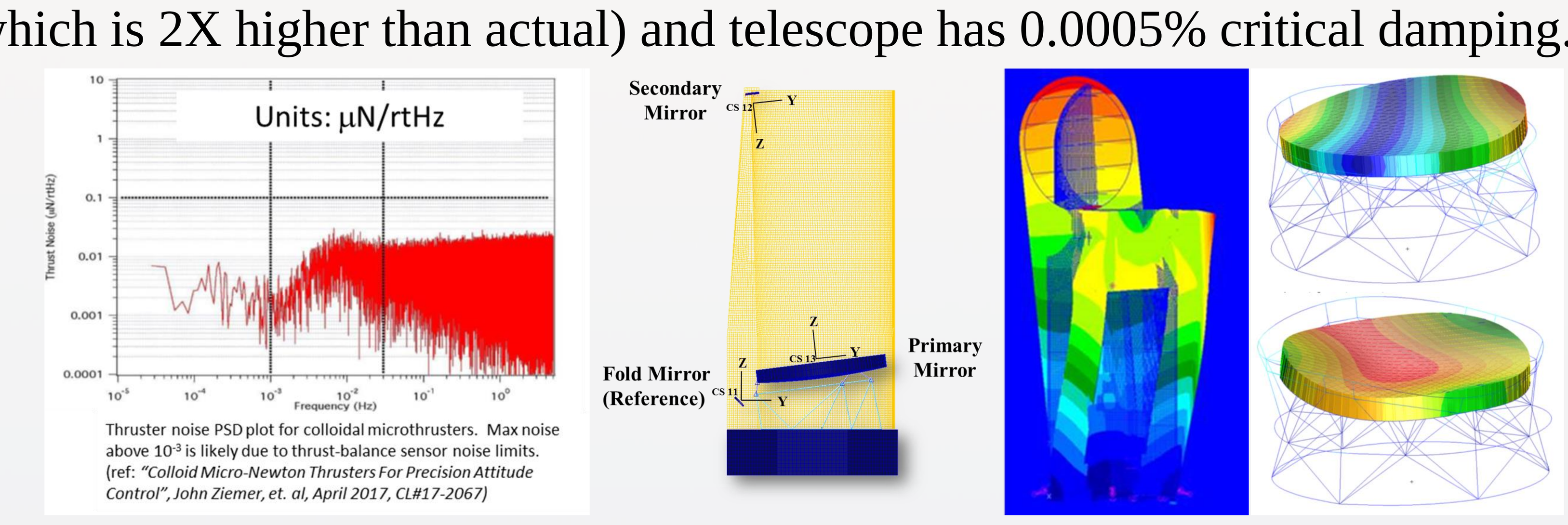
Zernike polynomial Error budget was derived for a Vector Vortex Coronagraph Charge-6 using science-driven systems-engineering. First step is to calculate the maximum allowable coronagraph contrast leakage which enables the detection (at a defined signal to noise ratio of an exoplanet with a given flux ratio relative to its host star). Second step is to allocate that contrast leakage to Zernike terms based upon the VVC-6 sensitivity to that term and that term's likelihood of occurrence.

Index			Predicted Performance Amplitude [pm rms]			Total WFE	VVC-6 Sensitivity	Raw Contrast	Allocation	WFE Tolerance	Margin
N	M	Aberration	LOS	Inertial	Thermal	[pm rms]	[ppt/pm PV]	[ppt]	[ppt]	[pm RMS]	
		TOTAL RMS	5.715	3.994	5.565	8.921		7.289	30.000	36.715	
1	1	Tilt	3.025	0.123	0.026	3.027	0.0002	0.001	0.005	12.459	4.1
2	0	Power (Defocus)	0.728	1.430	3.759	4.087	0.0003	0.002	0.010	16.821	4.1
2	2	Astigmatism	4.674	3.559	3.463	6.819	0.0002	0.003	0.013	28.066	4.1
3	1	Coma	1.064	0.099	0.345	1.123	0.0002	0.001	0.002	4.620	4.1
4	0	Spherical	0.005	0.213	0.405	0.458	0.0003	0.000	0.001	1.883	4.1
3	3	Trefoil	0.050	1.039	2.098	2.342	1.0016	6.634	27.303	9.638	4.1
4	2	Sec Astigmatism	0.019	0.178	0.108	0.209	1.6495	1.091	4.489	0.861	4.1
5	1	Sec Coma	0.003	0.026	0.105	0.108	1.6645	0.624	2.568	0.445	4.1
6	0	Sec Spherical	0.000	0.028	0.000	0.028	2.8902	0.214	0.881	0.115	4.1
4	4	Tetrafoil	0.001	0.198	0.189	0.274	0.9312	0.806	3.317	1.127	4.1
5	3	Sec Trefoil	0.000	0.112	0.233	0.259	1.8200	1.630	6.708	1.064	4.1
6	2	Ter Astigmatism	0.000	0.021	0.000	0.021	2.7219	0.214	0.880	0.086	4.1
7	1	Ter Coma	0.000	0.033	0.000	0.033	3.0608	0.404	1.663	0.136	4.1
5	5	Pentafoil	0.000	0.074	0.217	0.229	2.4409	1.939	7.979	0.944	4.1
6	4	Sec Tetrafoil	0.000	0.029	0.000	0.029	2.2050	0.239	0.985	0.119	4.1
7	3	Ter Trefoil	0.000	0.015	0.000	0.015	2.7946	0.168	0.690	0.062	4.1
6	6	Hexafoil	0.000	0.026	0.000	0.026	3.1667	0.308	1.268	0.107	4.1
7	5	Sec Pentafoil	0.000	0.015	0.000	0.015	3.0694	0.184	0.758	0.062	4.1
7	7	Septafoil	0.000	0.010	0.000	0.010	2.6510	0.106	0.436	0.041	4.1

STOP modeling predicts that the HabEx baseline telescope's WFE Stability (from LOS, Inertial and Thermal) meets the specified error budget performance to image and characterize at exoEarth at 10-pc with a margin of greater than 4X.

MECHANICAL STABILITY

Micro-thruster noise can excite telescope modes – causing LOS jitter and WFE instability. STOP modeling calculated rigid body motion between primary, secondary and tertiary mirrors; and inertial bending of primary mirror on its mount. Analysis assumes that each head has a flat 0.1 micro-Newton noise spectrum (which is 2X higher than actual) and telescope has 0.0005% critical damping.

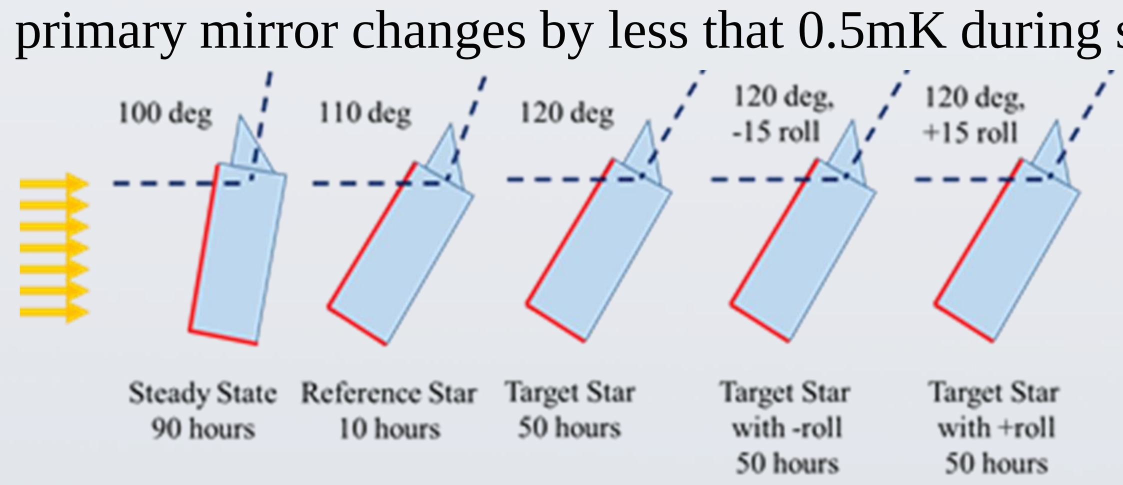


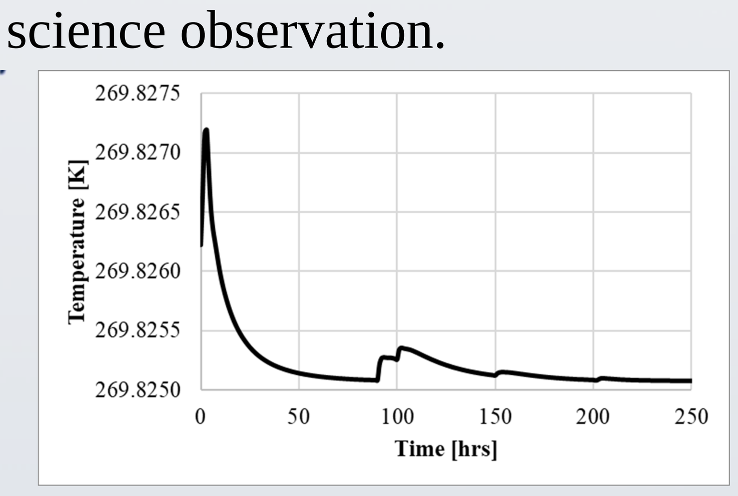
Predicted mechanical rigid body motion results in 0.03 mas of on-sky LOS jitter and 5.7 pm rms of LOS WFE instability.

Predicted total Inertial WFE instability is 4.0 pm rms.

THERMAL STABILITY

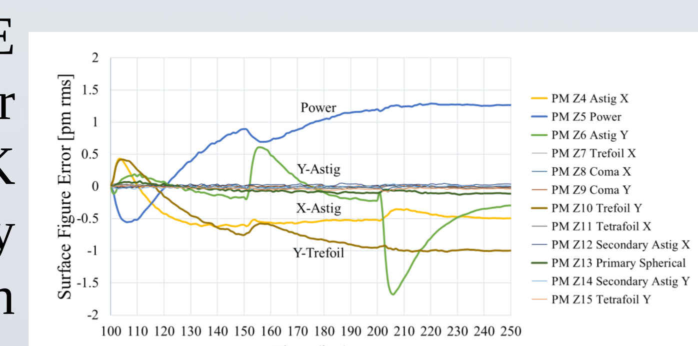
Sun orientation changes during observation run can change structure dimensions and mirror shape resulting in LOS drift and WFE instability. STOP modeling calculated predictions that for a 'stressing' 250 hour design reference mission the primary mirror changes by less that 0.5mK during science observation.





Predicted thermal rigid body motion is sensed and corrected by laser metrology system. Residual 'uncorrected' error results in 0.2 mas of on-sky LOS drift

Analysis predicts 5.6 pm rms of Thermal WFE instability caused by a Zerodur® primary mirror with 30 ppb/K bulk CTE and ±5 ppb/K inhomogeneity. WFE Stability is provided by primary mirror's mass, passive thermal isolation and active thermal control of mirror and structure.



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